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**INVESTIGATION OF SOLDER CRACKING PROBLEMS
ON PRINTED CIRCUIT BOARDS**

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RESEARCH AND DEVELOPMENT OPERATIONS
QUALITY AND RELIABILITY ASSURANCE LABORATORY

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ABSTRACT

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A Solder Committee designated to investigate a solder cracking phenomena occurring on the SATURN electrical/electronic hardware found the cause to be induced stress in the soldered connections rather than faulty soldering techniques. The design of the printed circuit (PC) board assemblies did not allow for thermal expansion of the boards that occurred during normal operation. The difference between the thermal expansion properties of the boards and component lead materials caused stress and cracking in the soldered connections.

The failure mechanism and various PC board component mounting configurations are examined in this report. Effective rework techniques using flanged tubelets, copper tubelets, and soft copper wiring are detailed. Future design considerations to provide adequate strain relief in mounting configurations are included to ensure successful solder terminations.

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SUMMARY

A Solder Committee was designated to investigate a solder cracking phenomena that was occurring on the SATURN electrical/electronic hardware. It was found that the cause was due to the design of the printed circuit (PC) board assemblies and not faulty soldering techniques. The design did not allow for thermal expansion of the printed circuit board during normal operating conditions and the different expansion characteristics of the board and component leads induced stress in the soldered connections resulting in cracking. The failure mechanism and various PC board component mounting configurations are examined in this report.

Effective techniques using flanged tubelets, copper tubelets, and soft copper wiring are detailed. Future design considerations to provide adequate strain relief in mounting configurations are included to ensure successful solder terminations.

A. THE FAILURE MECHANISM

1. The relatively high thermal coefficient of expansion of glass-epoxy printed circuit (PC) board, through which electronic component leads are routed, is the failure mechanism that is currently causing cracked solder joints. With few exceptions the cracks developed in the solder, not adjacent to the leads. The thermal coefficient of expansion of the fiberglass board is approximately a magnitude higher than the most common component lead materials used today.

2. As seen in figure 1, any thermal excursion is accompanied by a change in PC board hole length and simultaneous change in component lead length. Thus any differences in the thermal coefficients of expansion will generate a force at both soldered connections. Obvious factors that affect the degree of cracking are: the thickness of the PC board (L_i), the temperature cycling that the PC board has been subjected to (ΔT), and the difference of coefficients of thermal expansion of the lead material and the glass-epoxy board. The temperature-expansion relationship is as follows:

$$L_f = L_i + \alpha (T_f - T_i) L_i$$

$$\alpha \left(\begin{array}{c} \text{Fiberglass} \\ \text{PC Board} \end{array} \right) = 60 \times 10^{-6} \text{ in. / (in.) } (^{\circ}\text{C})$$

$$\alpha \left(\begin{array}{c} \text{component} \\ \text{lead} \end{array} \right) = 7 \times 10^{-6} \text{ in. / (in.) } (^{\circ}\text{C})$$

L_i = Initial length at temperature T_i

L_f = Final length at temperature T_f

α = Thermal coefficient of expansion

3. Thus, it can be seen that even a small change in temperature, as experienced "on the shelf" during storage, can cause stressing in a solder joint. The smaller the ΔT , the smaller the applied stress. However, according to the metallurgical characteristics of solder, it does not require a great force to cause a creep-rupture type failure in a soldered connection. Reports by the IBM and Martin Companies indicate this failure mode can be induced with less than a two pound force in a time frame of a week or less.

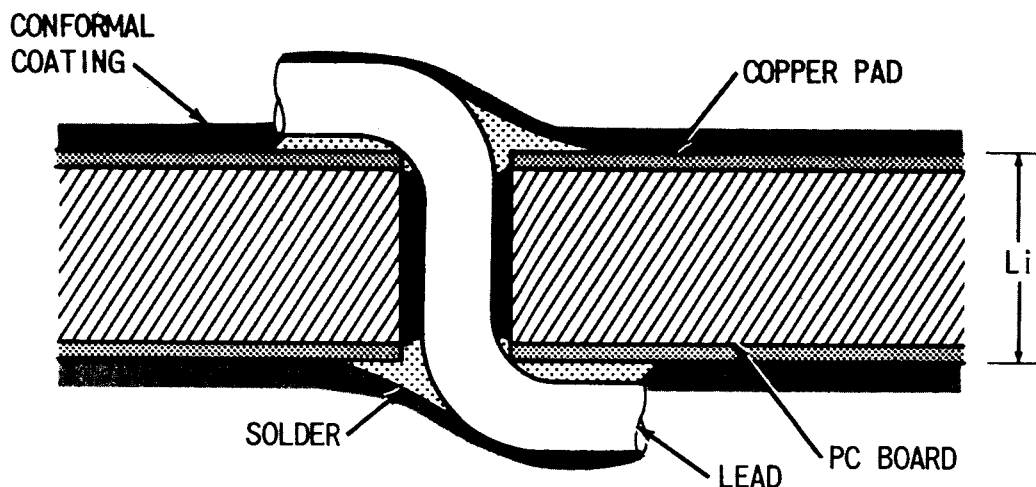


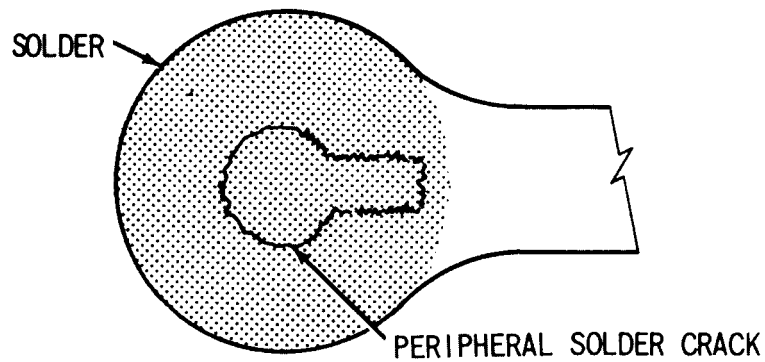
Figure 1. Temperature-Expansion Relation

B. COMPONENT MOUNTING CONFIGURATIONS

1. One of the more frequent failure modes noted during this investigation was as depicted in figure 2. Both techniques (A and B) attempt to confine the expansion of the glass-epoxy board when a temperature differential appears and induces stress in the soldered connections. Figure 3A shows a component lead being used for a circuit feed-through and is subject to the same failure mode as described in figure 2. For mounting configurations as shown in figure 3A, it was noted that the solder cracked on the component side of the PC board, thus indicating that a clinched lead is stronger than the stud or non-clinched lead terminations.

2. Components mounted as shown in figure 3B seemed to produce little or no stress on their soldered connections. Strain relief is apparent on the component side of the PC board and conformal coating thickness did not seem to affect the integrity of the solder joint.

DETAIL I



DETAIL I

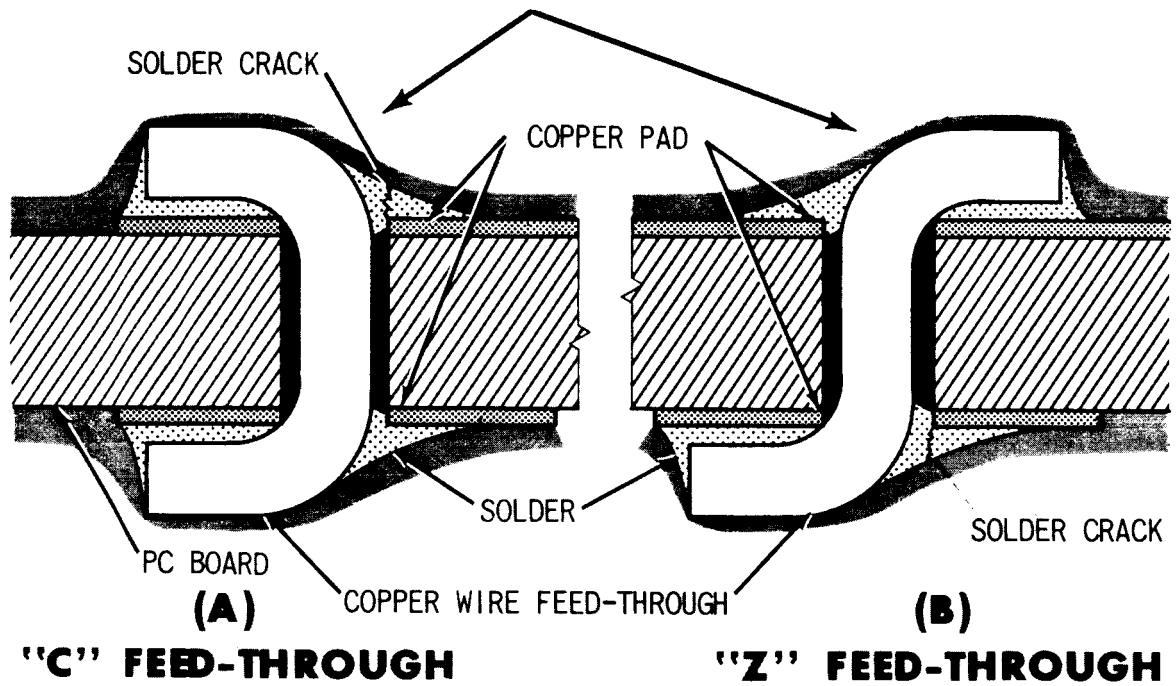
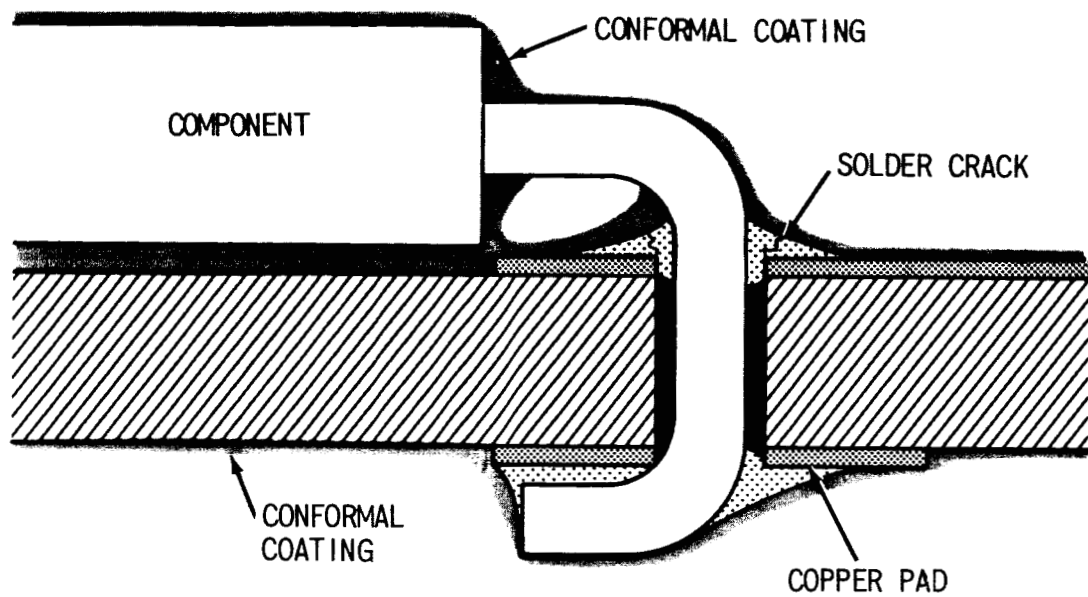
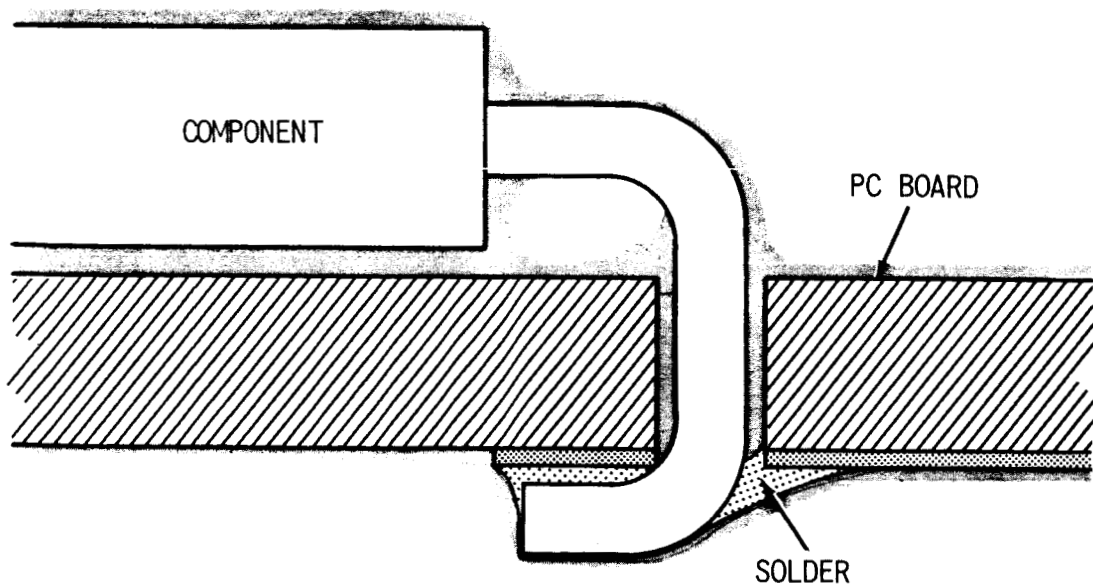


Figure 2. Double-Sided Circuit Board Failure Modes



(A) DOUBLE-SIDED CIRCUIT BOARD



(B) SINGLE-SIDED CIRCUIT BOARD

Figure 3. Component Mounting

3. The typical transistor mounting technique when conformal coated is highly sensitive to solder cracking problems as shown in figure 4. This mounting method accounted for most of the cracked soldered connections observed during this solder joint investigation. The conformal coating tends to secure the component to the PC board (component lead is soldered to the other side of the PC board) and this action in conjunction with the effective increase in length of the PC board hole by the addition of the plastic spacer impregnated with polyurethane produces sufficient force to crack solder connections. In the absence of either the conformal coating or the plastic spacer, the forces generated during normal use are not great enough to crack their associated soldered connections.

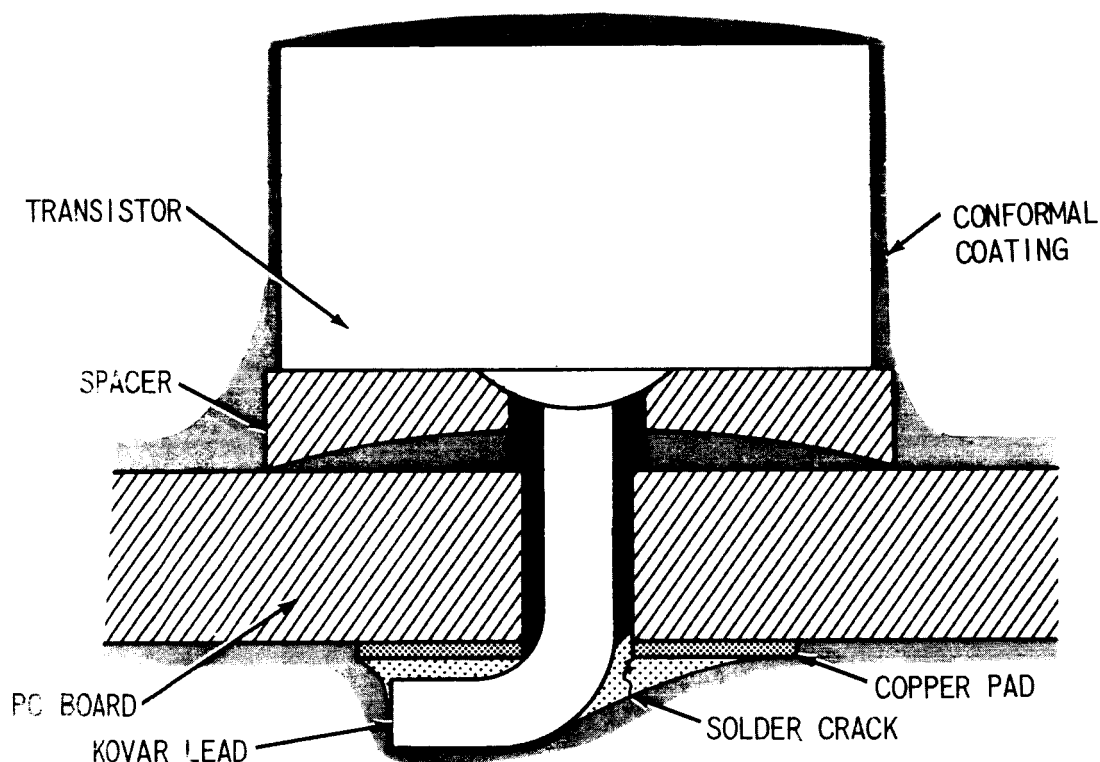


Figure 4. Transistor Mounting Configuration

4. The larger transistor case size (TO-5) is affected by this solder cracking mechanism more than the smaller case size (TO-18). One explanation for this fact is that the hole patterns drilled in PC boards are often the same for the TO-5 and TO-18 transistors and when routing the TO-18 leads into a hole pattern drilled for the larger TO-5, the leads

must be "spread-out" and thus strain relief is effected. Another factor may be the difference in the area of the two transistor cases. The conformal coating can exert more force on the larger case size than the smaller TO-18.

5. Figure 5A shows a stud or nonclinched lead. This mounting configuration is used when the leads are too heavy and thus not practical to clinch. Electronic components that fall into this category are relays, modules, and magnetics. However there are many exceptions where the leads are smaller and clinching is used as seen in figure 5B. The failure mechanism is very similar to figure 4. The component lead is soldered to one side of the PC board and secured via the case which is conformal coated on the other side. The solder usually cracks around the heel of the lead with the crack visible on the surface of the solder and outlining the PC pad hole and the clinched portion of the lead (crack progresses from the hole area to clinched lead area).

C. REWORK PROGRAM

1. A rework program has been initiated on several flight hardware items in order to remedy the cracked solder situation. All "fixes" performed to date employed the flanged tubelet, copper tubelet, or soft copper wiring. The tubelet methods provide more rugged connections that will withstand all applied external forces, while the soft copper wire provides a redundant path with strain relief. The tubelet installation repair is a much faster and easier repair than the soft wire technique and thus has seen broader usage.

2. During the early stages of the rework program, an important phenomenon was discovered which indicated caution must be exercised for all rework of soldered connections. The first indication of trouble was on a completely reworked PC board as it was being electrically functioned. This test indicated a low resistance path between a relay pin and its metal case. Additional testing revealed certain transistors (not using spacers in installation) also exhibited this same defect. Cross-sectioning revealed that solder had flowed down the relay pin and/or transistor lead and provided this low resistance path. This condition is shown on a relay in figure 6. Transistors that were installed with elevated spacers provided the necessary paths for the conformal coating (polyurethane) to saturate the glass header area thus preventing the above condition.

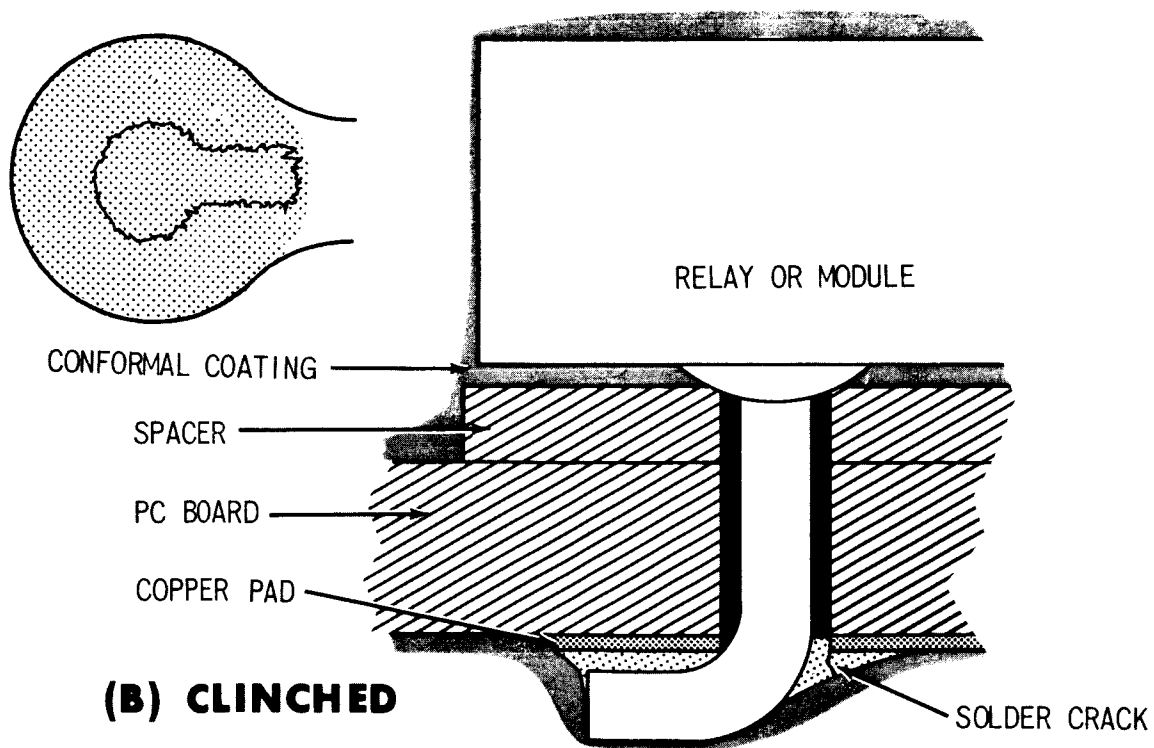
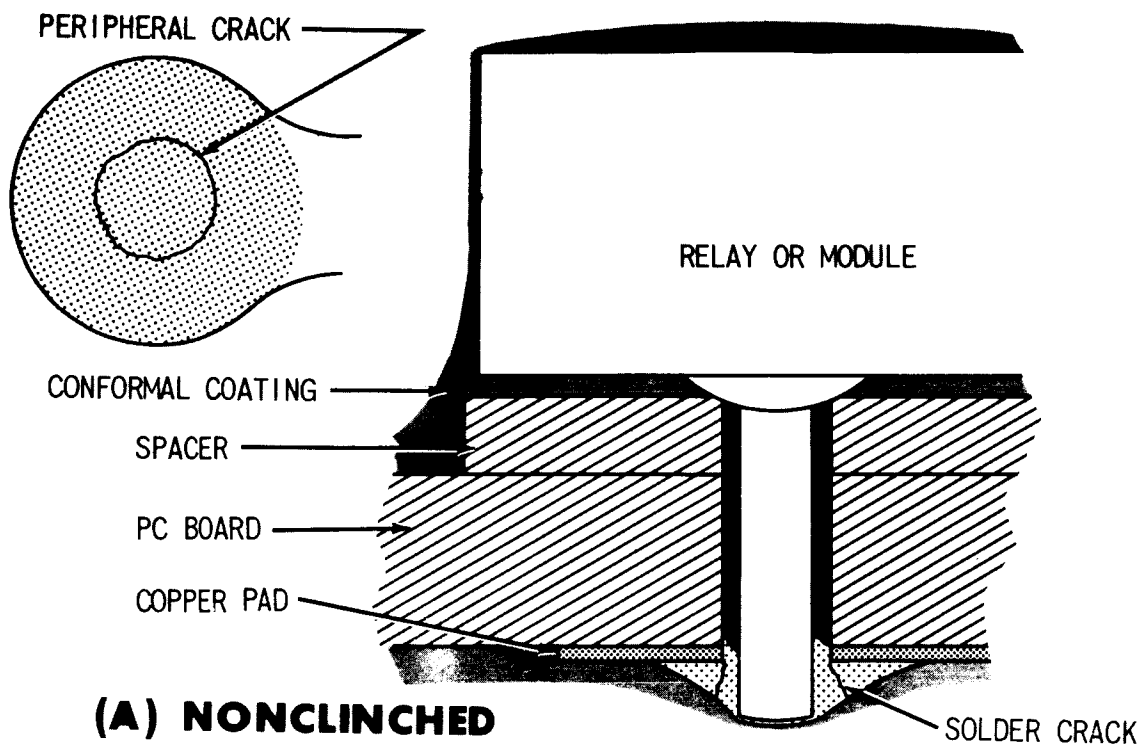


Figure 5. Relay or Module Mounting

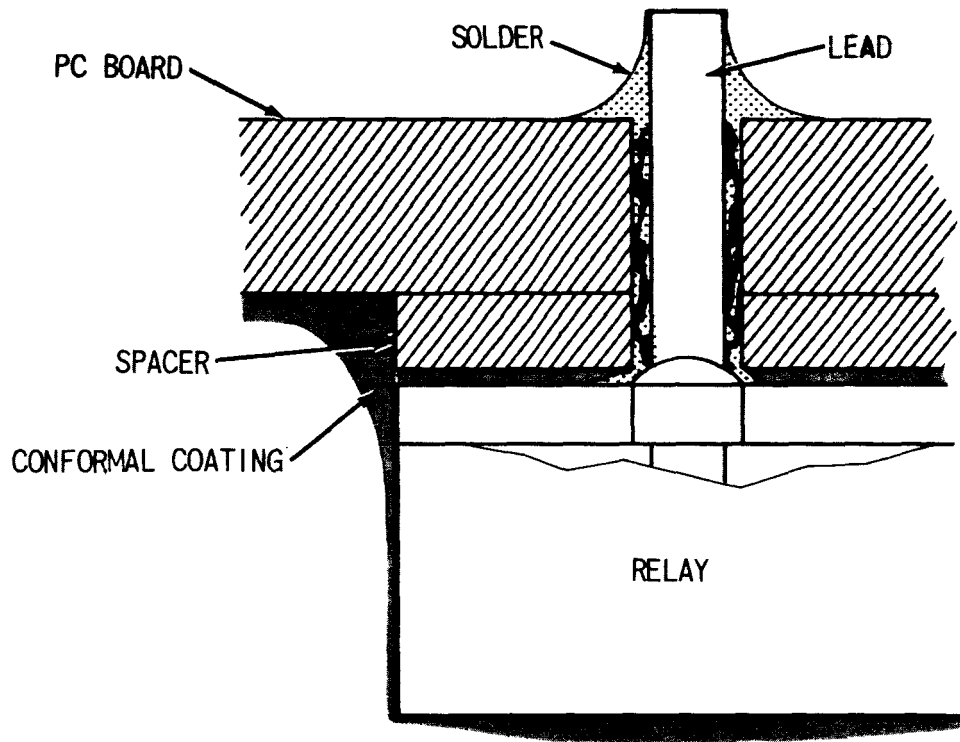


Figure 6. Relay Shorting Condition

3. The theory is when a PC board assembly is soldered and conformal coated a partial vacuum is produced in the PC board holes through which the component leads protrude. Then anytime heat is applied to a soldered connection, the partial vacuum tends to be relieved and, in the process, pulls molten solder into the low pressure area. If in the application of the conformal coating, it seeped between the component case and the spacer, this problem would not exist (the area around the glass bead is filled with polyurethane and solder cannot short the lead). Spacers that provide a channel for the polyurethane to reach the pin-to-case junction area ensure electrical isolation during the rework process. During any rework program it must be first ascertained if the conformal coating will provide adequate electrical isolation; and, if not, the components must be removed, soldering operations completed, and conformal coating re-applied.

4. The rework approach used for stud (nonclinched) mounted devices, such as relays, magnetics, and modules, utilizes a flanged tubelet (figure 7). First the conformal coating is removed and existing solder

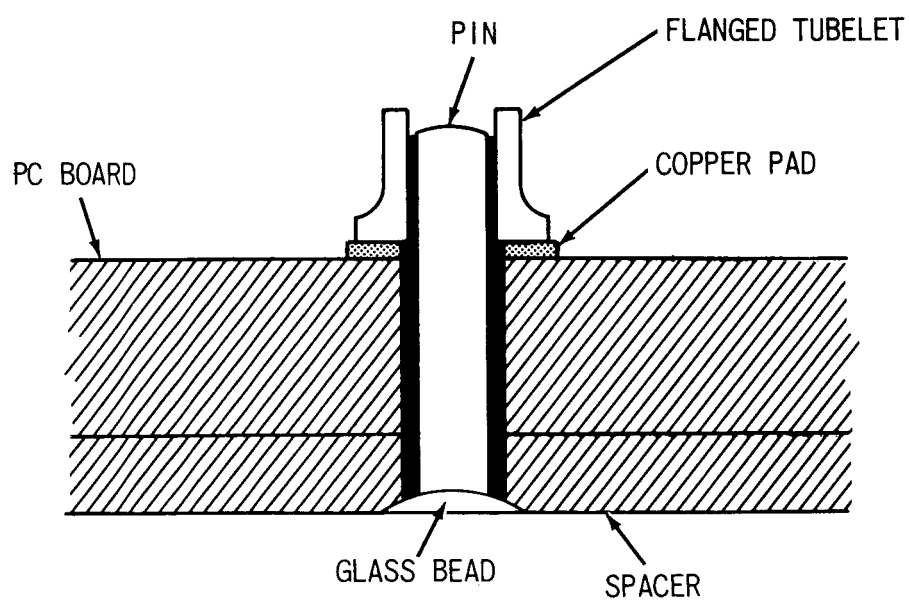
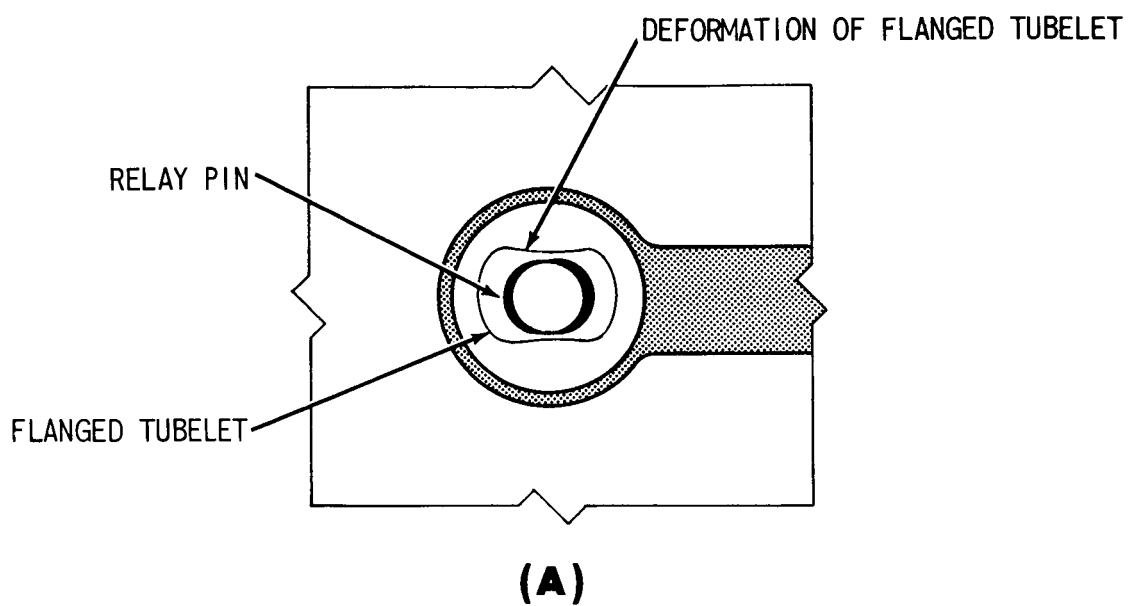


Figure 7. Flanged Tubelet Installation

wicked off. Depending on the conformal coating and spacers used on the PC board assembly construction components may have to be removed. Then the flanged tubelet is placed over the stud and resistance welded to the stud (note deformation caused by electrode on figure 7A); solder is then flowed between the copper PC pad and the flange of the tubelet, and between stud and barrel of tubelet. The rework approach for clinched devices is similar except a copper tubelet is used without resistance welding (figure 8).

5. The soft wire technique is shown in figure 9. This method provides a redundant path around the failure mode (figure 2B). The wire is soldered to the component lead, routed with strain relief, and soldered to the PC board copper circuit. Many variations of this method have been successfully employed to date.

D. FUTURE DESIGN CONSIDERATIONS

1. A number of recommendations oriented toward eliminating the cracked solder joint problem is given in paragraph E. However, it's paramount that a sample number of each of the completed PC board

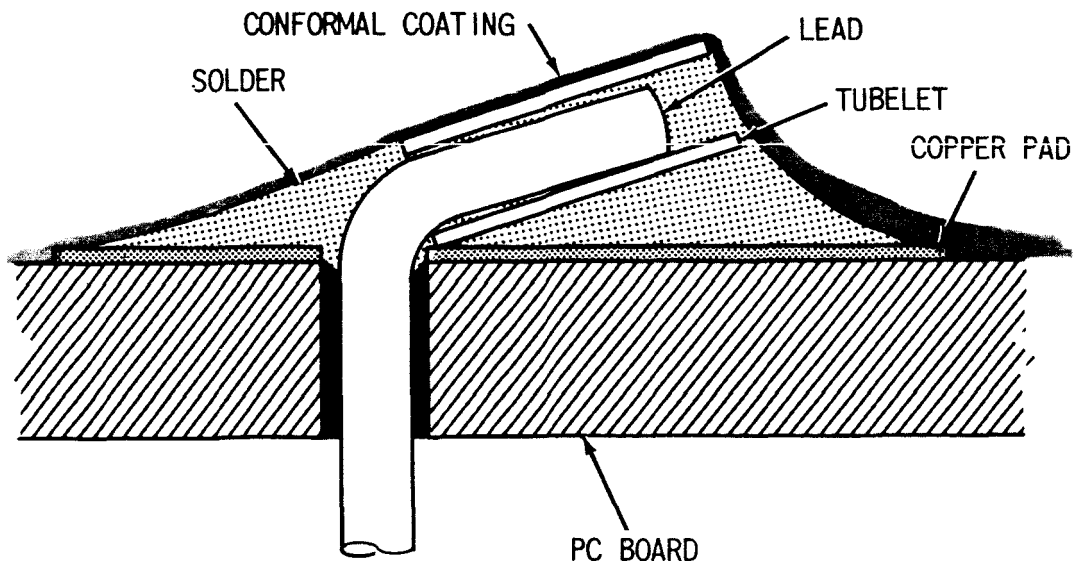


Figure 8. Copper Tubelet Installation

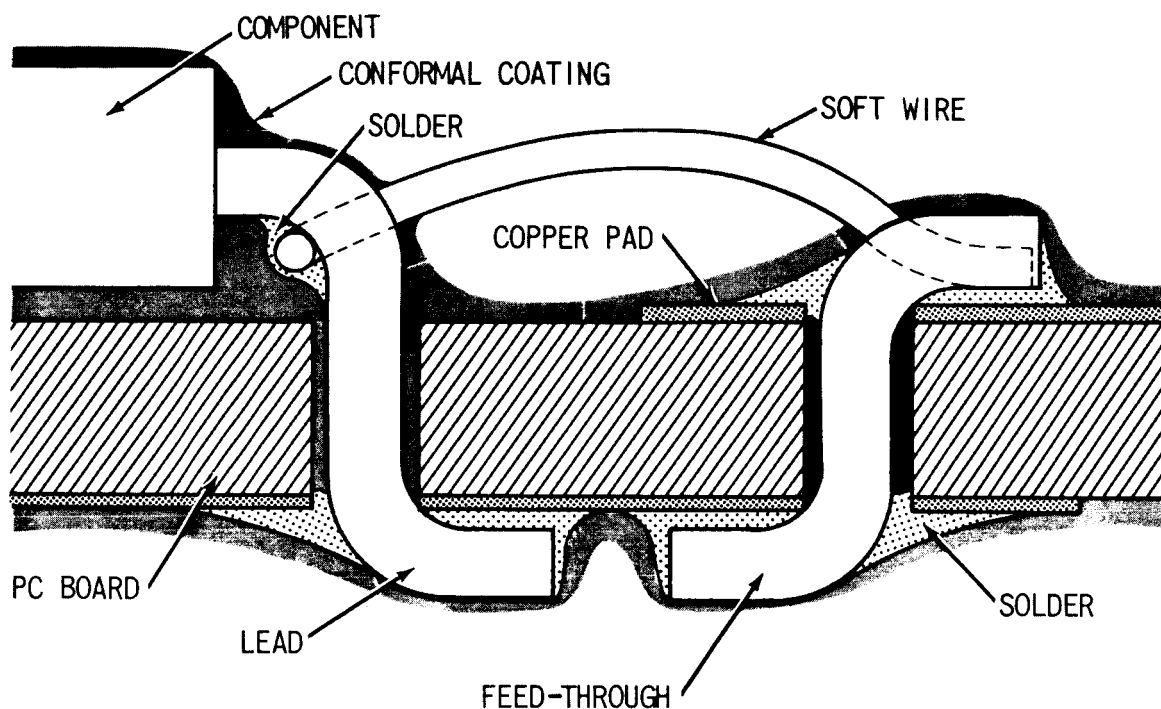


Figure 9. Soft Wire Modification

assemblies be temperature cycled and vibrated through expected levels for complete verification of all electrical connections. The following recommendations are based on judgement as well as experience and should be tested for each individual assembly. The interplay obtained by varying certain component mounting and soldering techniques makes it very difficult to predict the final solder joint integrity of any new or modified assembly without actual testing of hardware.

2. The key to successful solder terminations for any future design is to obtain and maintain strain relief throughout any temperature excursion envisioned for that particular assembly.

E. STRAIN RELIEF TECHNIQUES

1. A method that has received some testing in the Quality and Reliability Assurance Laboratory for providing strain relief for transistor mounting is shown in figure 10. The test configuration consisted of

four different hole-to-copper-pad spacings (S, figure 10). The test results (after 250 temperature cycles of -65° to 170°F) indicate that for S-values $3/16$ inch and greater no cracks and stresses appeared in the soldered connections. For S-values smaller than $3/16$ inch the number of defects progressively increases.

2. The transistor mounting configuration as shown in figure 11 was used on the RCA 110A computer to correct the failure mechanism causing cracked solder joints. The strain relieving C-bends in the leads were formed using a standard tool to ensure uniformity and a safe working distance from the transistor glass header. Tall spacers were required to incorporate C-bends.

3. A commonly used method for mounting relays and similar modules with strain relief is shown in figure 12. For circuit feed-throughs the preferred interconnection technique is shown in figure 13. When mounting components on a double-sided circuit board and using the component lead as a circuit feed-through, it is suggested that the technique shown in figure 14 be used.

4. If design is such that the above strain relief techniques can't be incorporated, the following conditions (found during PC board investigation) which were instrumental in preventing cracks should be employed.

(a) Maximum permissible solder on all joints that would normally require strain relief.

(b) Plated through-holes in all locations where strain relief would normally be incorporated.

(c) Spacers eliminated where possible, and if use is mandatory, thinnest possible spacers utilized.

(d) Conformal coating as thin as practical.

NOTE

Conformal coating is also used as a ruggedizing agent and vibration levels may have to be re-qualified when a thinner coating is used.

(e) Reinforcement of solder joints with tubelet or flanged tubelet (paragraph C. 4.).

SIDE VIEW

CONFORMAL COATING

PC BOARD

TRANSISTOR

SPACER

COPPER PAD

KOVAR LEAD

SOLDER

PC BOARD

COPPER PAD

SOLDER

KOVAR LEAD

S

BOTTOM VIEW

14

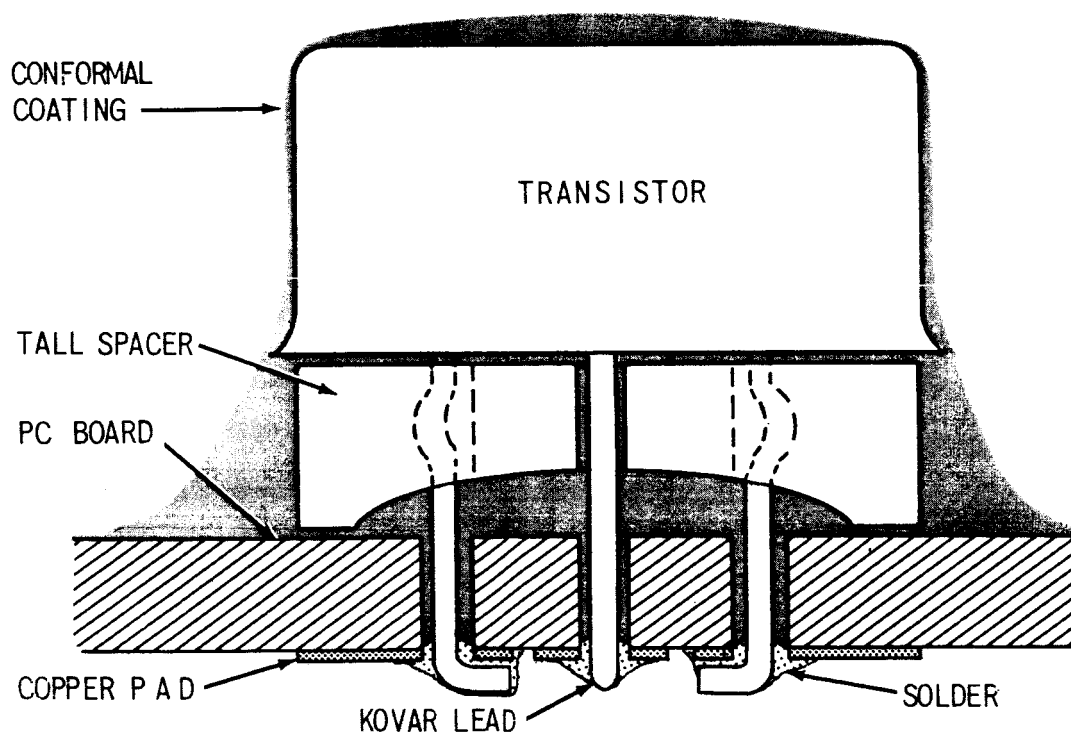


Figure 11. Transistor Mounting Using C-Bend Strain Relief

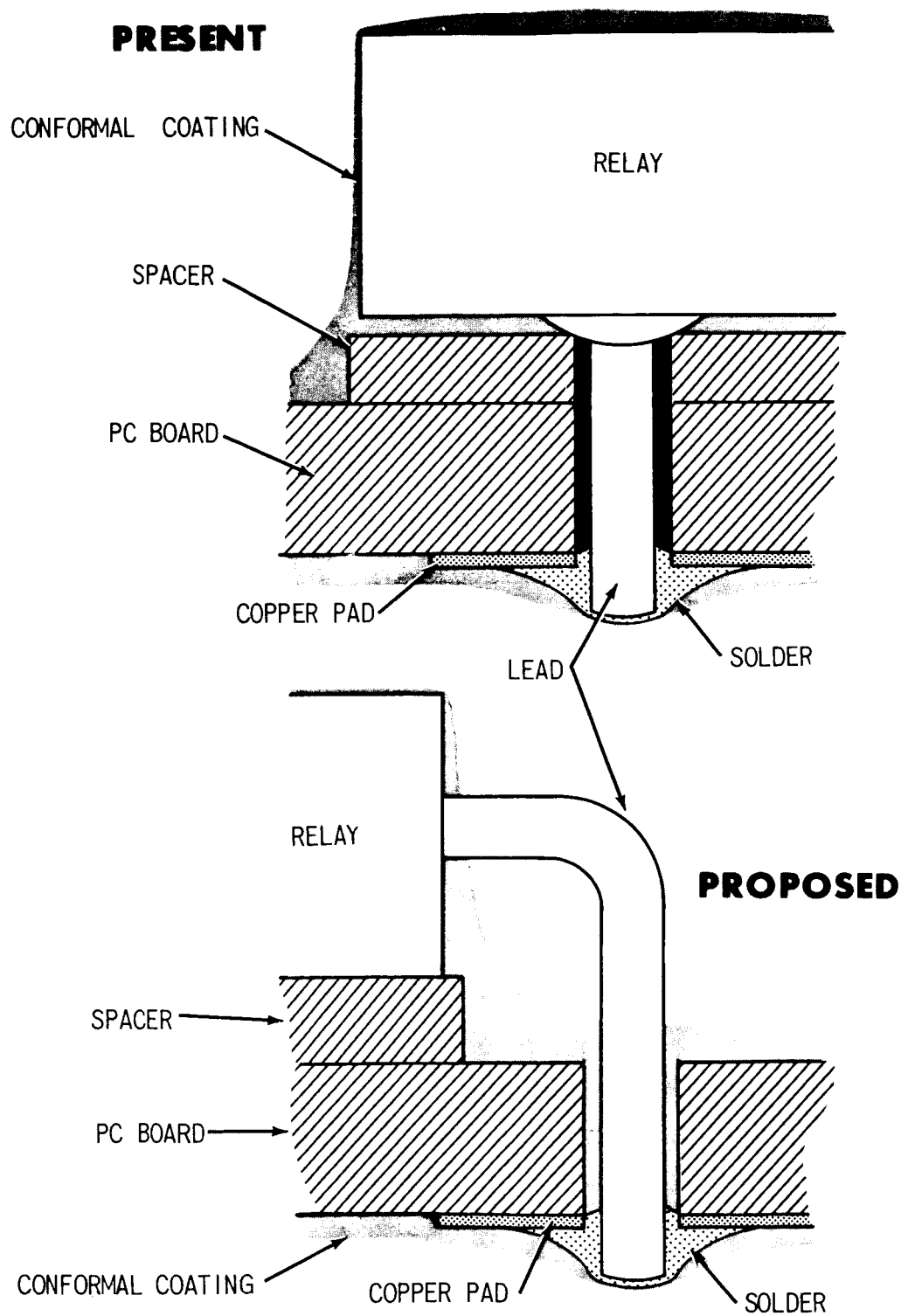
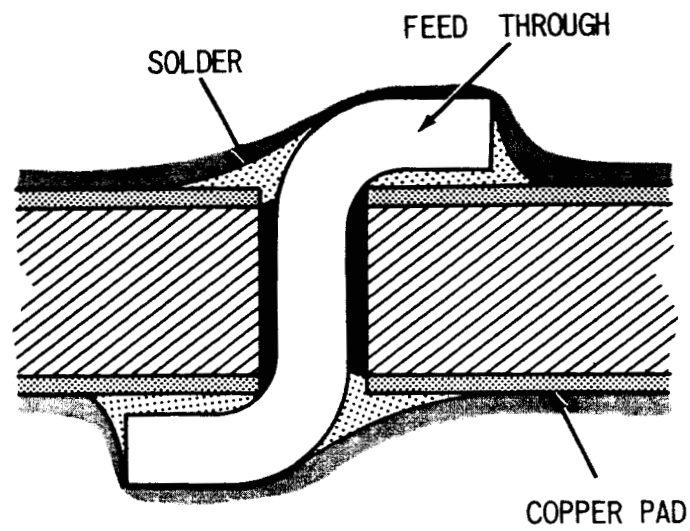
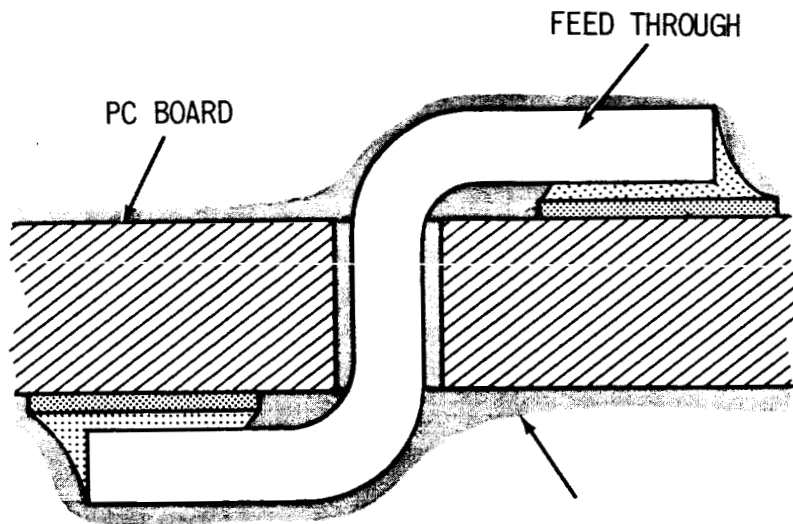


Figure 12. Relay (and Similar Modules) Mounting

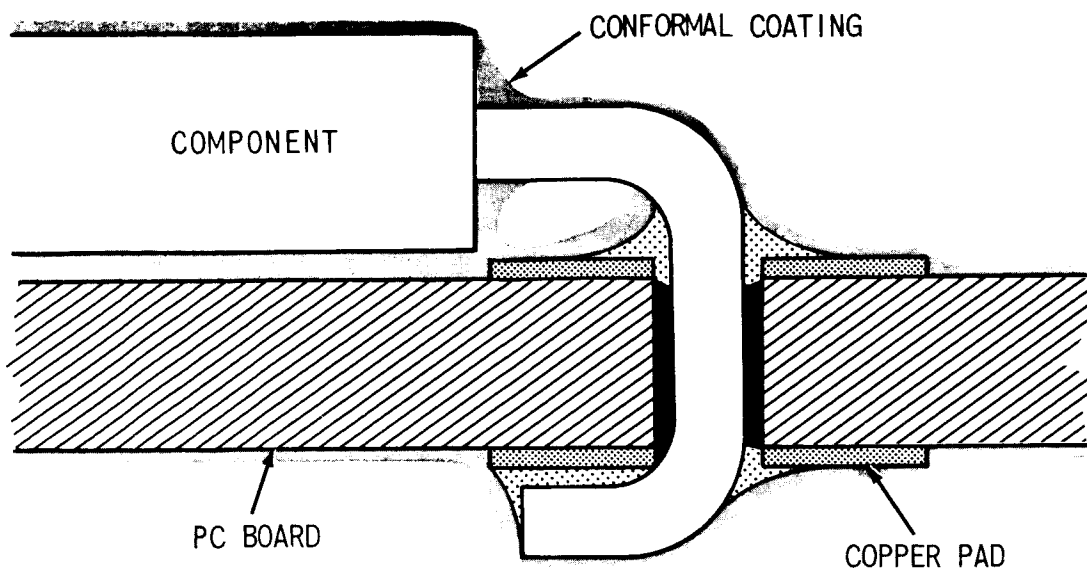


PRESENT

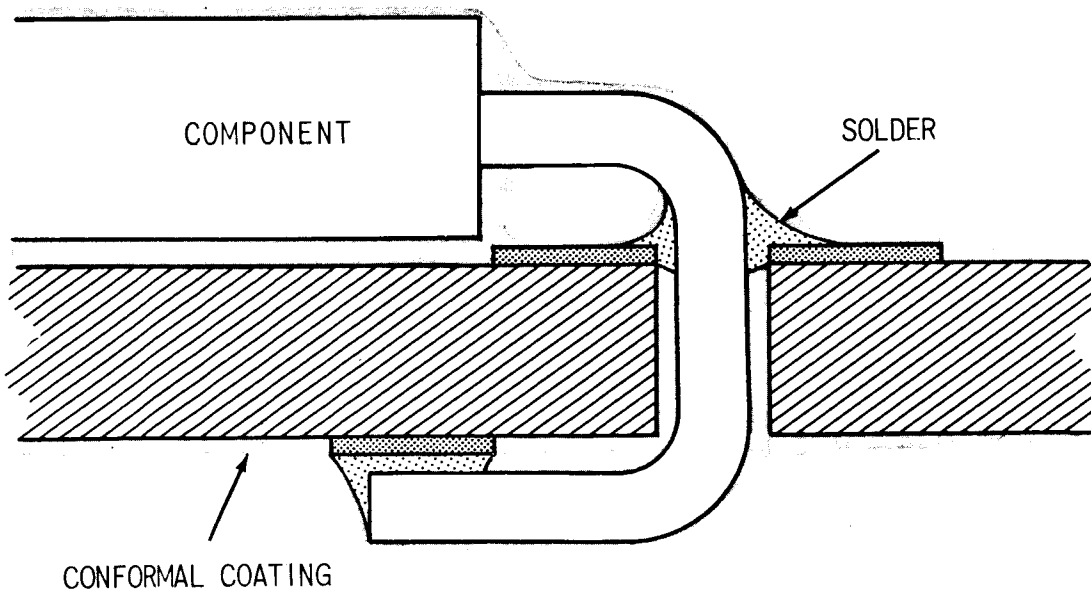


PROPOSED

Figure 13. Circuit Feed-Through Interconnection Technique



PRESENT



PROPOSED

Figure 14. Mounting Components on Double-Sided Circuit Board Using Component Lead as Circuit Feed-Through

(f) Redundant wiring (paragraph C. 5.).

(g) Components with highly solderable lead material and avoiding any brittle intermetallic structure, such as gold enriched solder or repeated solder operations on a given conductor or circuit pattern.

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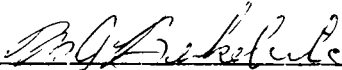
APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.



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